

An Investigation of Ballast Water Management Methods with Particular Emphasis on the Risks of the Sequential Method

Synopsis

Ship owners, managers and builders will be aware that a number of port states including Australia, Canada, Chile, Israel, New Zealand and the USA have introduced regulations intended to prevent ships which arrive in their waters from discharging ballast water which contains “non-native, harmful species of aquatic life forms”. The masters of such ships are expected to demonstrate that they have taken steps to prevent such discharge by some means which is acceptable to the relevant port state.

LR carried out an investigation on the various ballast water management methods with particular emphasis on the risks of the sequential method. LR, prompted by the fact that issues pertinent to the sequential method have not yet been fully appreciated by the industry, commenced a two-part study using 26 existing ships of various types, configurations and sizes. The objective of the first part of the study was to investigate the effects of the sequential method on the ship's structure and the assessment criteria in respect of classification, statutory and operational aspects. The objective of the second part of the study was the development of a safe operational envelope, on the basis of sea-keeping analysis, to control the dynamic effects for the ballast condition under consideration. Overall, the study serves as a reference guide for Administrations who intend to develop ballast water management policies. The investigation raises serious concerns for the safety of most existing ship types and configurations using the sequential method of ballast water exchange and options to mitigate such risks are discussed.

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1 Introduction

Ships that carry large quantities of a particular cargo are invariably forced to spend time at sea without any such cargo. To achieve a seaworthy condition in terms of stability, trim and strength, seawater is taken on board to form the ballast condition, which is of a somewhat lighter displacement than the full load condition. For those ships carrying general cargo, partially loaded conditions are common and water ballast is also used to adjust trim, heel and stability of the ship to compensate for the non-homogeneous loading condition.

The International Maritime Organization has estimated that every year the world's fleet moves ten billion tonnes of ballast water around the world and that on average more than 3000 species of plants

and animals are being transported daily around the world. Once these are introduced to local environment, it is virtually impossible to get rid of them. This could have a permanent effect on the environment, which could bring a catastrophic effect on local fisheries. It is therefore imperative that introduction of harmful aquatic organisms is prevented rather than cured afterwards.

Whilst harmful aquatic organisms are also transported on the bottom of a bio-fouled hull and on the anchor chain cable, it would appear that the Administrations have decided to deal with the transfer of harmful aquatic organisms in ballast water. The Administrations perceive that the solution to this problem is ballast water management.

2 Ballast Water Management Methods

The ballast water management methods fall under three categories, the exchange, the treatment and the isolation of ballast water (fig. 1).

IMO currently recognizes two ballast water exchange at sea methods, the sequential and the flow-through.

The sequential method is defined as when a ballast tank is emptied and refilled. When this method is utilized, the pumping and piping systems undergo an increased workload. The effective exchange of almost the complete volume of ballast water has resulted in the perception that the sequential method is an effective way of prohibiting the transfer of harmful aquatic organisms. However, this method requires careful planning and monitoring by the ship's staff to mitigate the risks imposed on the ship in respect of longitudinal strength, dynamic loads, excessive trim, bottom forward slamming, propeller emergence, intact stability and bridge visibility.

The flow-through method is defined as when replacement water is pumped into the ballast tank allowing the water to overflow. It has been reported that such a method could be effective only if the water pumped-in equals several times the volume of the tank. Approximate figures so far indicate a 95% and 98% water exchange after pumping-in water equivalent to three and four tank volumes respectively, assuming perfect mixing conditions. Some tank configurations, such as the double bottom and peak tanks, could be difficult to flush through effectively and may require pipe work to improve mixing. Care is needed in the application of this method which could result in the resizing of pumps due to the increased resistance and higher workload, fitting of new pumping and piping systems, over-pressurization leading to structural damage and icing on deck in sub-zero temperature conditions.

Research is currently conducted world-wide on the development of efficient and effective ballast water treatment methods. Some of the concerns regarding the treatment methods are as follows:

- Mechanical treatment: clogging of filters, not effective for small organisms, disposal of the collected residues, limited space on existing ships, resizing of the pumps may be required to cope with the increased filter resistance.
- Physical treatment: health and safety aspects for crew, additional pipe work, adverse effect on tank coating, pipes and pumps which could lead to corrosion, discharge of heated water may be undesirable for environmental reasons.

- Chemical treatment: health and safety aspects for crew, limited space on existing ships, adverse effect on tank coating, pipes and pumps which could lead to corrosion, discharge of treated water may be undesirable for environmental reasons.

No treatment method has yet been recognized at international level. Whilst there are obvious financial gains for research companies investing in such methods, it may prove legislatively difficult for Administrations to identify individual products, unless there are clear standards against which these are assessed. A possible way ahead is by some kind of international type approval.

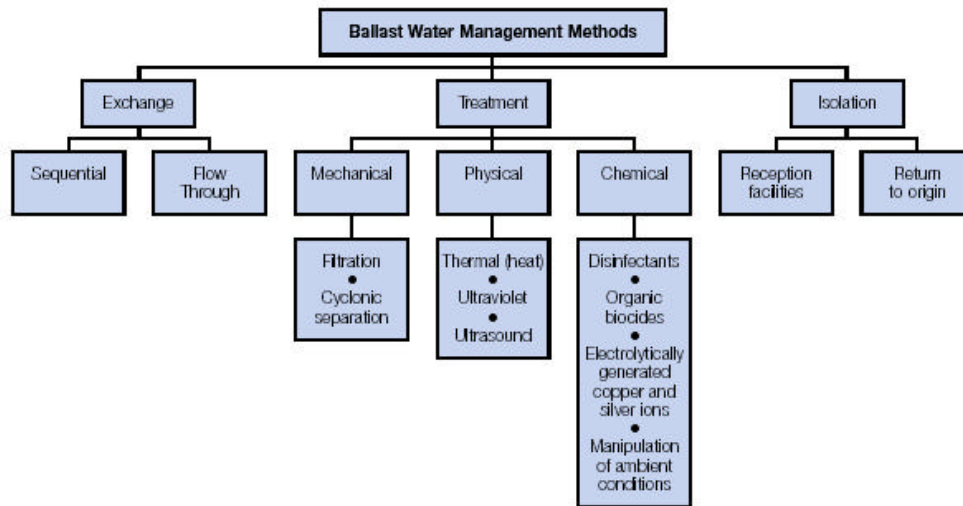


Figure 1 – Ballast water management methods

Discharging to reception facilities would avoid the problems of the exchange and the flow-through methods. However, this method could force most ships to spend more time at port with an associated workload increase in the piping and pumping systems.

Discharging to the location where ballast was taken in would be impractical in most cases, since retention on board is not feasible for all ship types, especially for deadweight carriers. This method could introduce additional time spent at sea.

3 Instigation of the LR Study

In November 1997, IMO, having regard to the safety implications for ships undertaking ballast water exchange at sea, published the *Resolution A.868(20), Guidelines for the Control and Management of Ship's Ballast Water to Minimize the Transfer of Harmful Aquatic Organisms and Pathogens*.

These guidelines introduce the concept of a 'ballast water management plan' (BWMP), specific to each ship, which would contain information and guidance intended to provide safe and effective procedures for ballast water management, especially with regard to ballast water exchange at sea, the safety aspects of which are described in an appendix to the Resolution.

IMO currently recognizes two methods for ballast water exchange at sea; the flow-through and the sequential. A key aspect of the ballast exchange philosophy is the assumption that mid-ocean aquatic

life forms will not survive in coastal waters (and vice versa). It follows from this assumption that any ballast water exchange must take place in open deep waters.

Existing legislation in Australia, Canada, Chile, Israel, New Zealand and the USA requires ships to exchange or treat ballast at sea prior to entering port, coastal or state waters. This process is expected to be carried out according to the ship's BWMP.

At present, whilst IMO works on a definition of the approval mechanism of the BWMP, the BWMP is considered to be the responsibility of the Administration with whom the ship is registered (Flag State), whereas the criteria for acceptability of the ballast water management methods employed rests with the Administration within whose territorial jurisdiction the ship is intended to operate (Port or Coastal State).

The Administrations are introducing regulations for ballast exchange at sea which aim to provide a solution to a socioeconomic problem. However, since the majority of the world's fleet is not designed to function safely in the manner expected by the Administrations, these regulations will result in techno-economic problems, which need to be addressed and resolved.

LR, prompted by the fact that issues pertinent to the sequential method have not yet been fully appreciated by the industry, commenced a two-part study using 26 existing ships of various types, configurations and sizes. The objectives of the study are as follows:

- The objective of the first part of the study is to investigate the effects of the sequential method on the ship's structure and the assessment criteria in respect of classification, statutory and operational aspects.
- The objective of the second part of the study is the development of a safe operational envelope, on the basis of sea-keeping analysis, to control the dynamic effects for the ballast condition under consideration.

Overall, the study serves as a reference guide for Administrations who intend to develop ballast water management policies.

4 General Criteria

Criteria governing the sequential method could be related to classification, statutory and operational aspects. Classification aspects infer global and local strength. Statutory aspects infer stability and visibility. Operational aspects infer trim.

Classification aspects:

- Longitudinal strength (i.e. permissible still water bending moments, shear forces and cargo torque)
- Dynamic loads (i.e. fatigue, ballast inertia and sloshing in tanks)

Statutory aspects:

- Intact stability (i.e. metacentric height, etc.)
- Bridge visibility (i.e. sea surface limit from the conning position, etc.)

Operational aspects:

- Minimum draught forward (i.e. risk of bottom forward slamming)
- Propeller emergence (i.e. risk of temporary reduction of maneuverability and slamming aft)

Operational aspects are inter-linked with classification and statutory aspects.

5 The Study

In the course of the study, twenty-six ships of various types, configurations and sizes were considered. These included three single skin tankers, one double skin tanker, four double hull tankers, four single side skin bulk carriers, five container ships, two liquefied natural gas carriers, two self-discharging bulk carriers, three oil-bulk-ore carriers and two general cargo ships (Table 1). Both light and heavy ballast conditions were investigated in the departure and arrival conditions, using the sequential method for all ballast tanks. For the purposes of the study the following criteria have been considered:

- Assigned permissible still water bending moments and still water shear forces. The calculations were carried out for full and empty tanks assuming that the hull girder is in good condition.
- As an indication of the ship's intact stability, the metacentric height corrected for free surfaces was checked against the ship's minimum metacentric height at 20% and 50% fill levels, whilst port and starboard ballast tanks were assumed to be exchanged simultaneously in order to prevent heeling.

Table 1 Ships considered in the LR Study					
Ship type	Description	L x B x D [m]	Year	Total ballast capacity [m ³]	Dead weight [tonnes]
Oil Tanker					
	Single skin with two long. bulkheads	217 x 32.2 x 19.6	1990	40397	62485
	Single skin with two long. bulkheads	234 x 42.68 x 21.5	1990	59168	106679
	Single skin with two long. bulkheads	313 x 56.6 x 28.6	1996	122308	258076
	Double side	177 x 27.43 x 17	1988	19636	39988
	Double hull with a centreline bulkhead	173 x 32.2 x 17.8	1996	21865	47252
	Double hull	264 x 43.9 x 24.4	1992	73097	154970
	Double hull with two long. bulkheads	327 x 56.4 x 30.4	1993	119878	296900
	Double hull with two long. bulkheads	320 x 58 x 31	1998	132631	311189
Bulk Carrier					
	Handysize, single side skin	177 x 30.4 x 16.5	1996	26575	45654
	Panamax, single side skin	216 x 32.2 x 19.1	1994	35151	73236
	Capesize, single side skin	256 x 40.5 x 21.2	1996	55171	122301
	Capesize, single side skin	270 x 43.0 x 24.1	1994	85592	151301
Container Ship					
	1725 TEU	174 x 27.4 x 15.8	1998	9677	24554
	2668 TEU	225.5 x 32.2 x 18.8	1993	19199	47120
	3429 TEU	241.5 x 32.2 x 19.2	1996	13830	46350
	3842 TEU	246 x 32.25 x 19.3	1998	11991	48224
	4477 TEU	263 x 37.1 x 21.7	1996	19933	61428
Liquefied Natural Gas Carrier					
	Membrane type	260 x 43.3 x 25.4	1997	46538	62500
	Moss type	276 x 46 x 25.5	1990	53751	78988
Self-Discharging Bulk Carrier					
	Double hull	170 x 27.6 x 16.1	1988	18576	36634
	Double hull	194 x 32 x 19	1993	33473	50587
Oil-Bulk-Ore Carrier					
	Double hull	200 x 32.2 x 17.35	1984	32851	54500
	Double hull	234 x 38 x 22.3	1991	61311	95000
	Double hull	275 x 45 x 25.9	1992	61436	169416
General Cargo					
	Multipurpose cargo ship	162 x 25.6 x 14.2	1999	6300	22948
	General cargo/container carrier	185 x 32.2 x 17	1984	11865	41600

- As an indication of the ship's bridge visibility, the view of the sea surface forward of the bow from the conning position was checked to be not more than two ship lengths or 500m whichever is the less. It is recognized that not all existing ships comply with *SOLAS 1974, Chapter V, Safety of navigation, Regulation 22, Navigation bridge visibility*. In such cases, existing ships are expected to comply in respect of forward view and blind sectors in so far as is practicable without structural alteration being required.
- Minimum draught forward as indicated in the ship's plans and/or loading manual. Where not mentioned, this was taken as 0,045L.
- Propeller immersion (top dead centre of propeller in still water).

Dynamic loads were investigated separately for selected cases. The derived maximum lifetime pressures were compared with the pressures derived from *ShipRight Structural Design Assessment Ultimate Strength Program (10604)*, with and without allowable diminutions and excluding hull girder effects.

Table 3
Double Hull Oil Tanker – OT6 – Heavy Ballast Departure

STEP	MODE	TST BTM	BWT	BWT	BWT	BWT	HOLD	BWT	BWT	BWT	T _{ACT}	T _{RED}	P _{AM}	SWBM	SWSF	Bridge Visibility
			APT	NO 5	NO 4	NO 3	5	NO 2	NO 1	FPT	(m)	(m)	(m)	-	-	-
0											10.42	10.14	2.05	OK	OK	OK
1	SEQUENTIAL										10.16	10.28	1.79	OK	OK	OK
2	SEQUENTIAL										8.91	10.91	-0.06	OK	OK	OK
3	SEQUENTIAL										7.72	10.52	-0.65	OK	OK	OK
4	SEQUENTIAL										9.25	9.17	0.88	OK	OK	OK
5	SEQUENTIAL										10.78	7.83	2.41	OK	OK	OK
6	SEQUENTIAL										12.22	6.56	3.85	NOT OK	OK	NOT OK
7	SEQUENTIAL										11.81	7.00	3.44	NOT OK	OK	NOT OK
8	SEQUENTIAL										9.14	7.74	0.77	OK	OK	OK
0											10.42	10.14	2.05	OK	OK	OK
Capacities [m³]			1735.3	5576.8	10306.0	10557.4	18581.3	10557.4	10466.0	5315.9						
RI [%]			28	100	100	100	100	100	100	100						

■ Ballast water before exchange
 ■ Empty
 ■ Exchanged ballast water

6 Findings

Regarding use of the sequential method only, the following findings can be deduced.

6.1 Longitudinal Strength

- All single skin tankers and oil-bulk-ore carriers indicated insufficient longitudinal strength.
- Some double hull tankers indicated insufficient longitudinal strength.
- Single side skin bulk carriers indicated that longitudinal strength could be sufficient only in the light ballast condition.
- One of the two self-discharging bulk carriers indicated insufficient vertical bending strength.
- Container ships indicated sufficient longitudinal strength. However, it should be noted that such ships rarely operate in *ballast only* conditions, since containers are normally loaded and off-loaded at each port. Ballast is allocated during the course of the voyage to accommodate changes in the distribution of cargo and consumables.
- Liquefied natural gas carriers indicated sufficient longitudinal strength.
- General cargo ships indicated sufficient longitudinal strength only in the ballast arrival condition.

6.2 Metacentric Height

- All cases indicated sufficient metacentric height corrected for free surfaces.

6.3 Sea View (fig. 2)

- In the light ballast condition, most cases indicated insufficient view of the sea surface forward of the bow from the conning position.
- Two tankers, one self-discharging bulk carrier and the two general cargo ships indicated sufficient view of the sea surface forward of the bow from the conning position.

6.4 Minimum Draught Forward

- Most cases resulted in draught forward less than the minimum draught forward value, which could result in bottom forward slamming.

6.5 Propeller Immersion

- Apart from container ships, most cases resulted in propeller emergence, which could result in temporary reduction of maneuverability and slamming aft.

6.6 Dynamic Loads – Fatigue

Emptying and refilling of a ballast tank imposes an additional load cycle. There is concern that the fatigue performance of the end connections of longitudinals could be reduced due to the increased number of loading cycles. For critical locations where the mean stress is shifted to a greater tensile stress, the fatigue life will be reduced. This matter needs to be investigated in future studies.

6.7 Dynamic Loads – Ballast Inertia

For bulk carriers, the combination of full ballast holds and empty topside and hopper tanks may induce dynamic loads, which could exceed the capability of the sloped bulkhead structures (fig. 3).

6.8 Dynamic Loads – Sloshing

Regarding sloshing in partially filled topside and hopper ballast tanks and ballast holds of single skin bulk carriers, the following general findings can be deduced:

- Partial filling of ballast holds should be avoided (fig. 4).
- Partial filling of topside tanks should be avoided in light ballast conditions (fig. 5).
- Partially filled hopper tanks should not give rise to sloshing concerns.

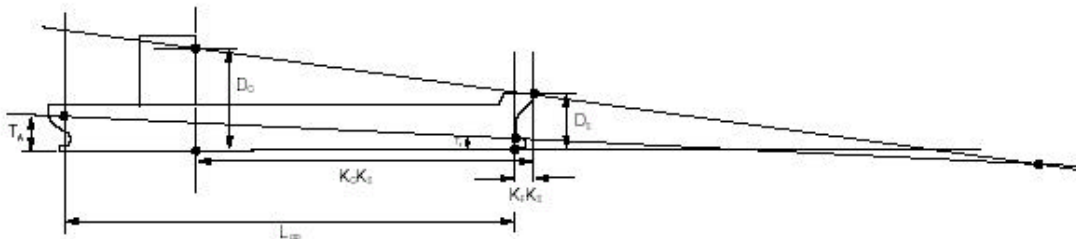


Figure 2 – View of the sea surface forward of the bow from the conning position

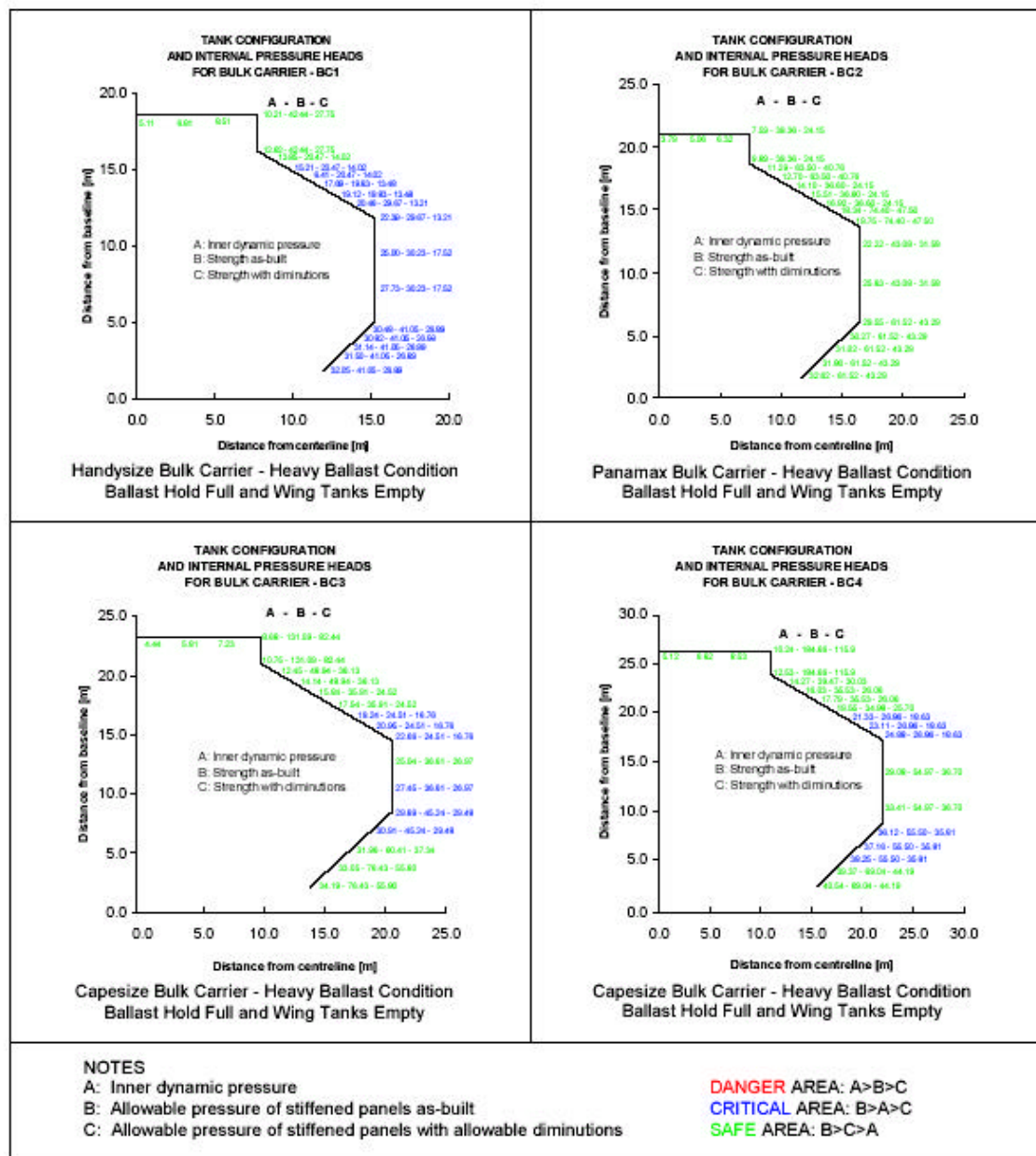


Figure 3 – Bulk carrier configuration and ballast inertia pressures

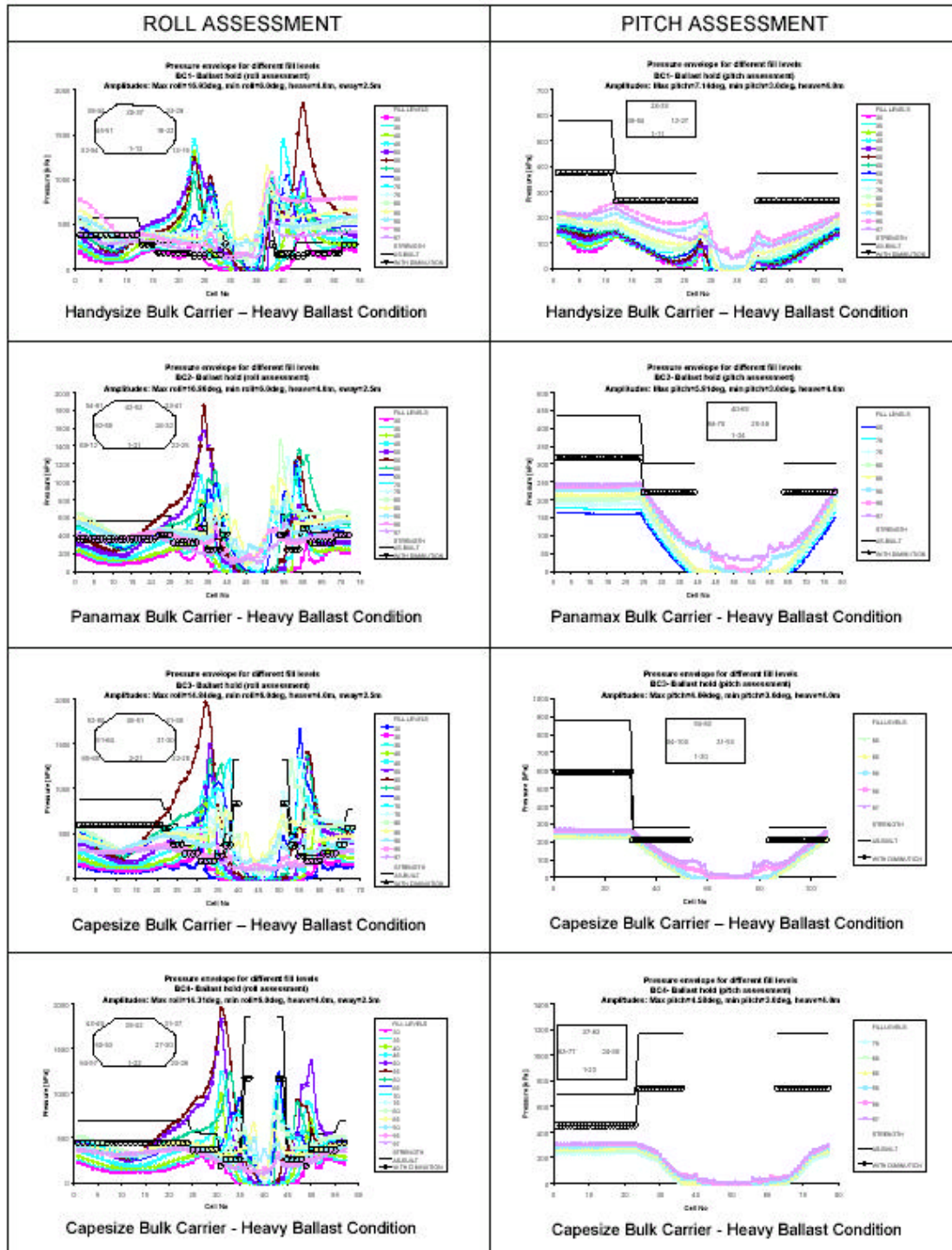


Figure 4 – Sloshing assessment of ballast holds

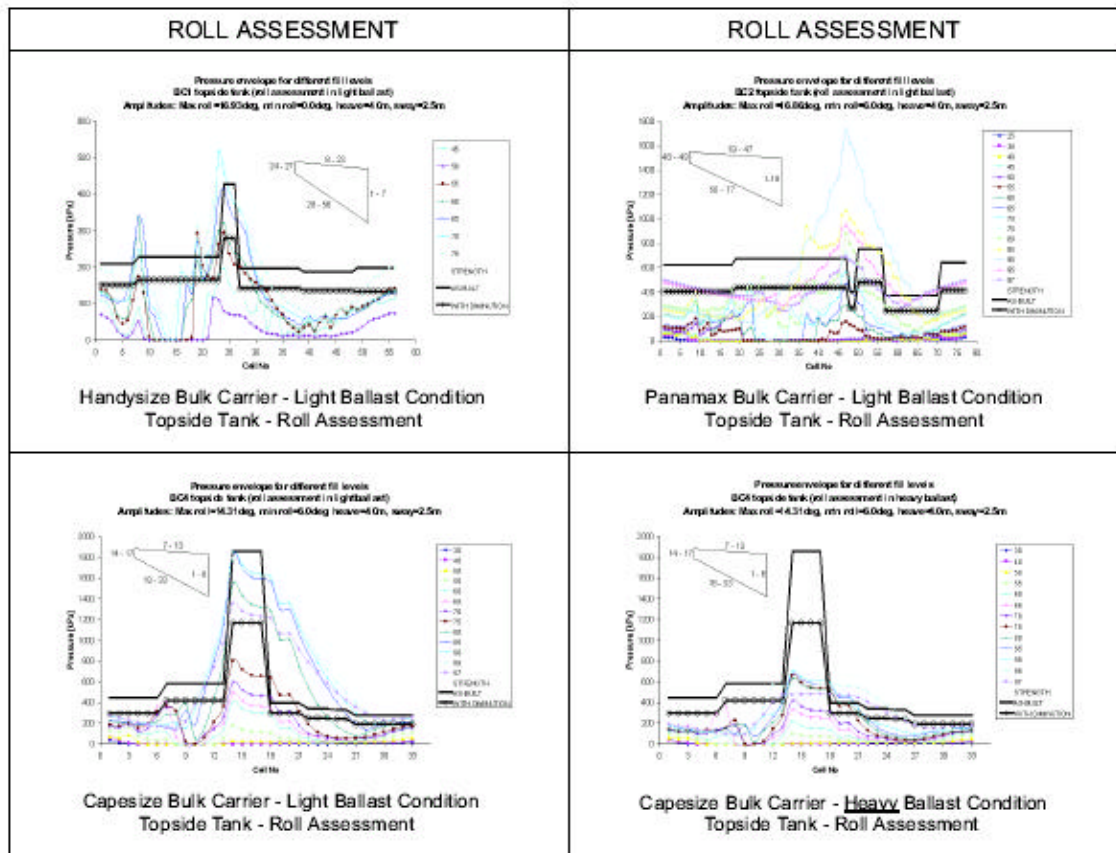


Figure 5 – Sloshing assessment of topside tanks

Regarding sloshing in partially filled ballast tanks of single skin oil tankers, the following general findings can be deduced:

- Partial filling of ballast tanks of single skin oil tankers should be avoided, unless the tanks are designed for unrestricted filling levels for the ballast condition under consideration.
- Wing ballast tanks of single skin oil tankers fitted with transverse ring web structures can be excluded from the sloshing investigation.

In addition, the following general comments are provided:

- Unless tanks are approved for unrestricted filling levels, a sloshing investigation may be required.
- Although LR's Level 1 sloshing analysis may indicate that sloshing is likely to occur, further analysis would be needed to assess the structural capability, which could be sufficient to withstand the maximum sloshing loads.
- Where tanks are tapered in plan view, such as the foremost and aftermost peak tanks, limited model experiments have indicated that in pitching, the dynamic pressure on the bulkhead at the narrow end can be magnified when compared with a tank of uniform section. Peak tanks fitted with a centerline wash bulkhead or a centreline ring structure or horizontal ring structures can be excluded from the sloshing investigation.
- Wash bulkheads, which represent more than 85% of the tank's cross sectional area, can be taken as being effective sloshing barriers.

- Where two or three frames or transverse members are fitted instead of a wash bulkhead, the pressure on the watertight bulkhead has been observed to decrease to about 80% of the dynamic pressure obtained without frames or transverse members. The dynamic pressure is not found to decrease further with increasing numbers of frames or transverse members.
- Sloshing need not be investigated for double bottom tanks and double side tanks for all ships and hopper tanks of bulk carriers.
- Sloshing need not be investigated for topside tanks of bulk carriers in the heavy ballast condition.

7 Options to Mitigate Risks

Administrations who accept the sequential method have not yet defined clear assessment methodologies and criteria.

Where the sequential method is utilized and the criteria are not achievable for all ballast spaces, consideration could be given to the adoption of one or a combination of the following options, **provided they are acceptable to the Administration(s) and the Operator**:

- Diagonal sequential method
- Flow-through method
- Operational envelope*
- Modifications
- Isolation
- Treatment

* Reference is made to the recent IMO document *MEPC 44/4*, which is the report of the IMO working group on ballast water. Of particular interest are regulations 13 and 15. Regulation 13 deals with a requirement for ships to have onboard a BWMP approved by the Administration. Regulation 15 deals with requirements for the structure and equipment of ships. Paragraph 15.1(c)iii refers to “favourable sea and swell conditions”. Paragraph 15.2 refers to procedures for ballast water management options which account for “admissible weather conditions”, “minimum/maximum forward and aft draughts so as to prevent slamming forward, maintain maneuverability and maintain bridge visibility”, “wave induced hull vibration”, etc. With the exception of “wave induced hull vibration”, which does not seem to have a clear assessment methodology and criterion, the other references indirectly refer to the development of an operational envelope to control dynamic effects. It is noted that the development of ship specific operational envelopes would require considerable manpower, even if appropriate procedures and software applications were available.

The question of performance standards has been raised at IMO by Greece who pointed out that it is necessary to develop an approval mechanism for alternative management techniques. According to Greece, the effectiveness of new techniques must be able to be compared with ballast water exchange and a systematic approach must be established. It is encouraging to see that this aspect appears in *MEPC 44/4* paragraph 2.10.2.

7.1 Diagonal Sequential Method

With this method, simultaneous emptying and refilling of closely matched diagonal tanks is carried out.

The feasibility of the diagonal sequential method was investigated for six ballast cases that did not comply with the criteria of the study.

It can be deduced that the diagonal sequential method could be an effective method for reducing the still water bending moment and shear force to within permissible levels. Simultaneous emptying and refilling of closely matched diagonal tanks will control heeling. The diagonal sequential method could induce hull girder torque which could be minimized, provided the selected tanks are relatively close and the ship's heading is as close as practicable to head seas.

7.2 Flow-through Method

Although there are risks and disadvantages with the flow-through method (see page 4), this method could be considered for tanks that fail to meet the criteria for sequential exchange, provided the scantlings of the tank boundary structure are designed for a tank head equivalent to the full distance to the top of the overflow.

Unless operational limits are specified, it can be deduced that the flow-through method could, in general, be needed for:

- the ballast holds of bulk carriers in the heavy ballast condition
- the topside tanks of bulk carriers in the light ballast condition
- the ballast tanks of single skin tankers
- the fore and aft peak tanks of bulk carriers and tankers

Where peak tanks are partially filled, the flow-through method should be avoided unless any inadvertent exceedance of the design partial filling levels will not result in hull girder bending moments and shear forces exceeding the permissible values.

Administrations who accept the flow-through method have not yet defined clear assessment criteria. Some Administrations require a minimum replacement of 95% of the original volume, yet fail to recognize that this figure may only be achieved or approached provided there is adequate flow in all areas of the tank, i.e. no areas of stagnation. Therefore, if the figure of 95% needs to be satisfied, a distributing grid of pipes would be required to ensure reasonably equal flows within the tank. It is estimated that retrofitting pipe work to this extent would be a considerable expense, especially for existing ships. In this respect and in the light of recent legislation of some American Coastal States (see page 16), investing in this method is likely to be seen by Operators, who need to trade in these waters, as a solution with limited potential. The retrofitting costs of a distributing grid of pipe work could balance or outweigh the installation costs of a treatment system when available in future.

7.3 Operational Envelope

It is considered that the present practice, whereby sequential ballast exchange conditions are approved on the basis of 'calm weather' or 'calm sea', is not practical for the 14 LR *Technical Association: Paper No. 1, Session 2000–2001* majority of Operators. It is noted that the World Meteorological Organization (WMO) defines a 'calm sea' as one where the significant wave height range is 0 – 0.1m. 'Calm seas' are rarely found in open deep waters and this leaves little margin for operations to be carried out effectively and safely.

It is recognized that the *IMO MEPC 44/4, Report of the Working Group on Ballast Water* convened during MEPC 43 makes reference to the ship's assigned permissible still water bending moments and shear forces. However, in order to satisfy these criteria many new sequences involving partially filled tanks may need to be introduced in the ballast exchange plan. This would imply that the ship's Master would have to ensure that the various filling levels are closely monitored and never exceeded. Such a ballast exchange plan could put a lot of strain on the ship's staff and, therefore, its practicality and safety implications could be questionable.

Solutions to these problems can be provided by managing the risks. This can be done by allowing the long-term criteria for longitudinal strength, sloshing, slamming and ballast inertia to be exceeded in the short term, provided the ship is operated within well-defined and acceptable operational limits. Where the strength criteria are not satisfied, limits can be defined in terms of response amplitude operators. Structural degradation, if any, can also be reflected in the derivation of the operational limits.

Taking into account the ship's actual hull form and weight distribution, direct calculations can be carried out for the derivation of response to regular waves by strip theory and short-term response to irregular waves using the sea spectrum concept. Subsequently, a solution can be developed in the format of an operational limit card. An operational limit card is defined in terms of permissible significant wave height and/or observed wave height, speed, heading, duration of operation and probability of exceedance of the specified limit. The combination of the selected limit cards produces the ship's operational envelope. The concept of the operational envelope is shown in fig. 6 in the form of a polar plot with 30 degree intervals, showing the permissible observed wave height in metres, for various speeds, in short-crested seas and in long-crested seas.

It is recognized that this approach could be laborious for each step of the sequential exchange. In this respect, LR has developed **LIMITS**, an in-house software package for sea keeping analysis and for the efficient derivation of operational envelopes. The operational envelopes could be ship specific or ship generic.

The operational envelope is a risk management approach solution and is based on self-regulation. Where operational limits have been defined for specific ballast exchange conditions, these would require to be adhered to during operation.

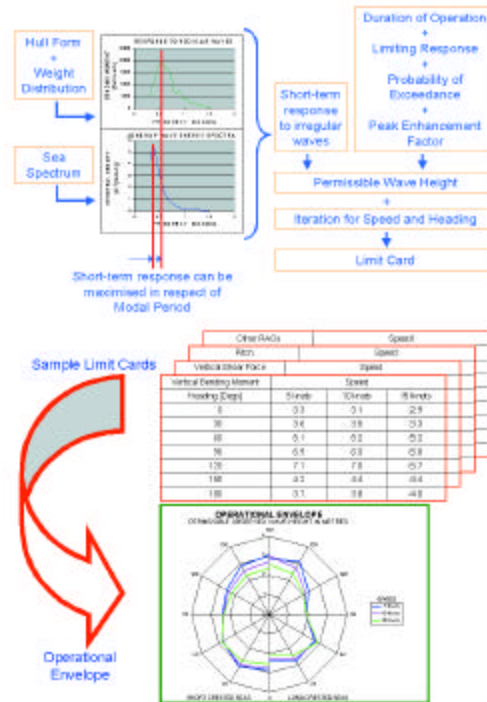


Figure 6 – The concept of operational envelope

7.4 Modifications

It is recognized that modifications may be needed in respect of the structure and/or engineering systems.

For flow-through systems, it is recommended that the inlet and outlet piping connections are located as remote as practicable from each other.

For flow-through systems, the double bottom and peak tanks may need additional pipe work to improve the mixing conditions.

For flow-through systems, the total sectional area of the ballast water discharge pipes on the upper deck should not be less than two times that of the sectional area of the filling/suction pipe. The size of one of the two ballast water discharge pipes on the opposite side of the filling/suction pipe should be bigger than the other ballast water discharge pipe. For instance, for a 250mmØ filling/suction pipe, 300mmØ and 200mmØ discharge pipes could be fitted.

Air pipes on ballast tanks are intended to allow air to escape, or enter, a tank during ballast operations and are usually of flat disc type or ball float (see fig. 7). They are not meant to be, or capable of, handling large-scale discharge of water ballast which can result from continuous ballast pumping as experienced in flow-through systems. Air vents with automatic closing devices are recommended.



Figure 7 – Air vent head with broken ball float

It is noted that where topside and hopper side tanks are not interconnected, the scantlings of the hopper and double bottom tanks are normally derived using the head to the top of the tank or half the distance to the top of the 15 LR *Technical Association: Paper No. 1, Session 2000–2001* overflow, whichever is the greater. Traditionally ballast tanks are filled until ballast water overflows. Subsequently, the water pressure at the tank bottom drops immediately due to entrapped air, which reduces the water level in an overflow pipe of a small diameter. However, the flow-through method will result in a constant high pressure during the long periods required to complete the operation. Therefore, for flow-through systems where topside and hopper side tanks are not interconnected, the scantlings of the tank boundary structure should be verified using a tank head equivalent to the full distance to the top of overflow.

Whilst damage to a ship due to over-pressurization of tanks appears an obvious possibility, it is sometimes overlooked that for sequential systems under-pressure could, in some cases, result in more severe damage. Under-pressure is created by a large drop in pressure, due to the rapid change in the contents of the tank. For instance, it is common on bulk carriers to discharge by gravity that part of the ballast above the load waterline through an overboard valve, which gives rise to a potential high vacuum due to the rapid rate of discharge. Unfortunately, air pipes alone do not have the capability of handling such large changes in pressure as those which occur due to discharge by gravity and, unless hold ventilators are open prior to discharge, then serious damage could occur.

For sequential systems, the increased frequency of partial ballast water discharges by gravity is likely to result in more damage incidents such as that shown in fig. 8.



Figure 8 – Vacuum damage in way of a ballast hold

It is anticipated that for sequential systems this kind of operation will be performed in open seas, probably far away from a safe haven, which makes the effect even more undesirable.

Operators need to take precautions to avoid being in this position.

Ballast holds are normally provided with adequate ventilators, which should ensure that the hold would not be subjected to excessive pressure or vacuum. For sequential systems, it is recommended that the bilge suctions are blanked, the blanks removed from the water ballast connections and the ventilator covers are kept open whenever the floodable hold is being used for the carriage of ballast, and during ballasting and deballasting. Similarly, before the hold reverts to the carriage of dry cargo the above blanking and unblanking process must be reversed.

For sequential systems, it is recommended that ballast holds and large ballast tanks are equipped with pressure/vacuum valves. These valves need to be maintained in good working order, as a chocked pressure/vacuum valve could result in hatch cover damage.

For sequential systems, where operational limits are specified, at least two independent pumps should be fitted. These should be arranged such that, if one pump fails, then the stand-by pump is immediately available for operation. It has been reported that most ships are equipped with two exclusive service pumps and, therefore, this recommendation may not have design ramifications for most ships in service.

Plans and particulars of any proposed modifications need to be submitted for approval before the work commences and the work is to be carried out in accordance with the approved plans to the Surveyors' satisfaction.

7.5 Isolation

It is considered that, for large passenger ships, the sequential method should not pose problems, since these ships often have limited ballast capacity that is used to compensate for usage of consumables. These ships could retain the ballast on-board and re-distribute it internally or exchange it during or at the end of the return voyage if navigating outside the Exclusive Economic Zone (EEZ).

It is noted that tankers utilizing the concept of Hydrostatic Balance Loading have restrictions on changing their draft and trim. In certain cargo loading conditions, where ballast is taken in, the ballast would have to remain on-board and be exchanged during the ballast leg of the voyage or, if feasible, discharged to reception facilities.

The option of reception facilities is seen as a very limited 16 LR *Technical Association: Paper No. 1, Session 2000–2001* solution since not many ports are likely to provide these. The Flotta terminal at Scapa Flow in the Orkney Islands, which can take ballast water from tankers, is a rare example although it has been reported that a design for an environmental treatment barge is under consideration in Norway.

7.6 Treatment

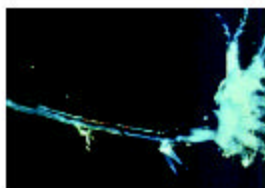
Any treatment system acceptable to the Administration(s) can be selected. However, what constitutes an acceptable method has not yet been clearly defined by the Administrations. Therefore, without specific internationally agreed criteria, what is acceptable to one Administration may not be acceptable to another now or in future.

Invasion of unwanted matter dates back to 1903 when a large mass of Asian phytoplankton was found in the North Sea. Recently reported invasions are given in Table 4 and typical critters are shown in fig. 9.

Table 4 Recently reported invasions			
Critter	Origin	Introduced to	First sighted
Zebra Mussel	Eurasia	Great Lakes	1980s
Ruffe	Eurasia	Great Lakes	1980s
Tropical Green Algae	Tropical Seas	Mediterranean Sea	1980s
Comb Jelly	US East Coast	Black Sea	1970s
Giant Fan Worm	Mediterranean Sea	Southern Australia Ports	1980s
Northern Pacific Seastar	Japan & Alaska	Tasmania, Australia	1986
Northern Pacific Kelp	Northern Pacific	Tasmania & Port Bay, Australia	1987
European Shore Crab	Europe	San Francisco Bay	Early 1990s
Round Goby	Caspian & Black Sea	Great Lakes	1995
Mitten Crab	China	San Francisco Bay	1992



Green crab



Spiny water flea



Ruffe



Zebra mussels basal threads



Rainbow jellyfish



Tubenose Goby

Figure 9 – Typical critters

Defining the *enemy* is not the only problem that Administrations are facing. Treatment systems, before being accepted as standard ship equipment, need to prove their effectiveness for specific *enemies*, i.e. to ensure that the *enemies* will not pose a threat after treatment.

It would appear that the United States Coast Guard (USCG) perceives treatment methods as being capable of achieving 100% exchange. It has been reported that in the medium to long term the USCG consider open ocean ballast exchange as only an interim measure; until such time as a suitable treatment technology is identified.

A Bill has been introduced in the Michigan legislature (Senate Bill No 955) to require that ships bringing ballast water into Michigan from outside the state must sterilize the ballast water and any sediments contained therein. Ships may not discharge unsterilized ballast water into Michigan waters. An exception is made for operations authorized by a state permit. The Michigan Department of Environmental Quality would be required to establish a ballast water inspection program and would be allowed to assess application and inspection fees. It has been reported that the ninth version of Bill 955 is underway which, realizing that sterilization is obviously not possible for all water and sediment in a tank, has opted for exchange, management practices and best available technology.

The California State Assembly Bill 703, as proposed by Assembly Member Lempert, requires zero discharge of live organisms. AB703 requires the sampling and monitoring of ballast water from a minimum of 10% of all vessels discharging ballast water in Californian waters. It also requires the following:

April 2000 to December 31, 2002

AB703 prohibits discharge of ballast water initially loaded from coastal waters outside the Pacific Coast Region into Californian Waters or waters that impact upon Californian Waters, without a Permit*.

*The Permit, which is obtained from the State Board, requires either:

(a) Carry out an adequate exchange of ballast water in open ocean waters. For the purposes of this section an adequate exchange is one that replaces at least 95% of the original volume of water in the tank with open ocean water.

Or

(b) Use an alternative environmentally sound method of ballast water treatment that has been approved by the Board and that it is at least as effective in removing or killing the exotic ballast water organisms in the initially loaded ballast water as the exchange described above, if that method is feasible.

From January 2003

AB703 prohibits discharge of ballast water containing live exotic organisms, into Californian waters by any vessel except by Special Permit**.

**The Special Permit is issued if:

Between January 1, 2003 and December 31, 2004

Vessels conform to (a) or (b) for the normal Permit (see above) and both the following:

(a) The applicant has commenced the construction or installation of facilities or mechanisms for treating or managing ballast water that will result, in the judgment of the Board, in the elimination of discharges containing live exotic ballast water organisms from all vessels to which the permit applies. And

(b) The applicant has provided the Board with a schedule for completion and implementation of those facilities or mechanisms on or before December 31, 2004.

From January 2005

The applicant is using facilities or mechanisms for treating or managing ballast water that will result, in the judgment of the Board, in the elimination of discharges containing live exotic ballast water organisms from all vessels to which the permit applies.

Although AB703 (Lempert) is supposed to be effective from April 2000, the California State has not yet clarified whether flow-through systems without a distributing grid of pipes are acceptable.

In 1991 there was a case of a large colony of mussels in Mobil Bay being contaminated by a ballast discharge containing Cholera. As a result of this type of incident, the issue of ballast water treatment has also had to focus on the threat posed by viruses as well as organisms. Physical separation technology should play a significant role in any ballast water treatment system but, according to those who work in the microscopic realm, no single technology can remove all life forms from ballast water. Ultraviolet radiation has played a key role in the field of microscopic disinfection for some time within the marine field and, therefore, it has been identified as having great potential with respect to ballast water treatment.

Ultraviolet is the part of the electromagnetic spectrum with waves shorter than light but longer than X-rays. Ultraviolet light consists of radiation in the ultraviolet and it is known to destroy the organic cells and proteins that form constituent components of a multitude of microscopic life forms. An example of such destruction is shown in fig. 10. Note the opaque appearance of the body in fig. 10(b) compared to that in fig. 10(a), signifying denaturing proteins as well as signs of a destroyed exoskeleton.

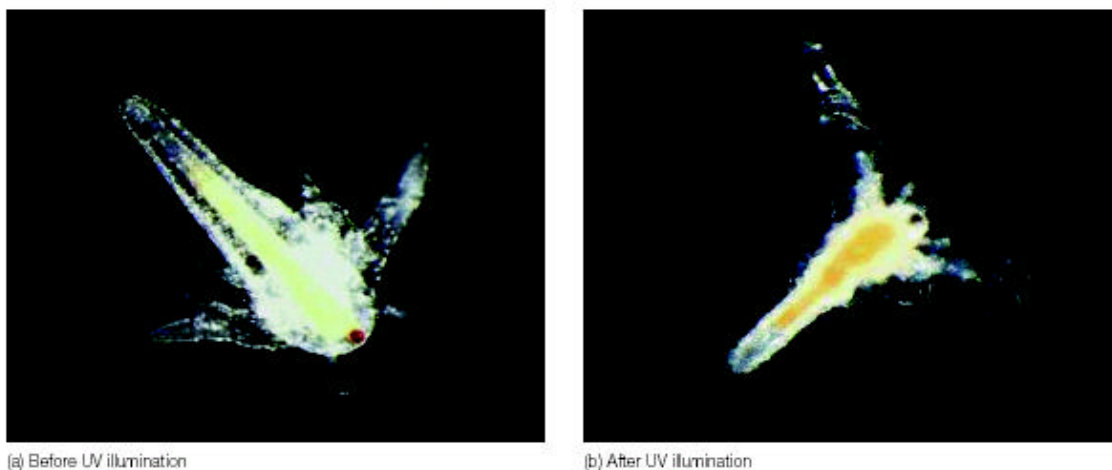


Figure 10 – Artemia Naupilus larva exposed to UV

Below the 50µm level, other key organisms such as the dinoflagellate *Prorocentrum Minimum* (fig. 11) would have a much lower chance of survival after a short exposure (few seconds) to ultraviolet radiation.

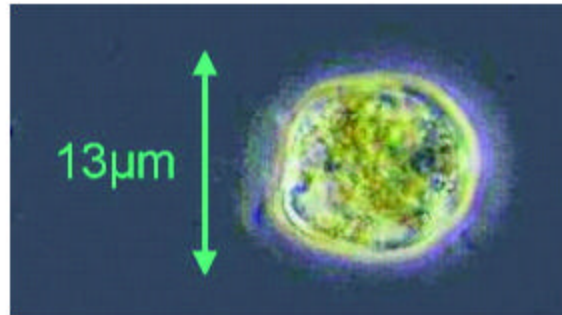


Figure 11 – *Prorocentrum Minimum*

Ultraviolet radiation represents “tried and tested” technology on ships and could be, generally, a relatively comfortable choice for many operators.

Above the 50µm level, it has been reported that there are self-cleaning filters which can accommodate flow rates of approx. 300m³/hour, incorporating self-cleaning devices such as brushes, for the removal of accumulated solids from the screen surfaces. During the screening cycle, back flushing could also be incorporated in order to facilitate the removal of solids. The space envelope required to accommodate such a filter would be in the region of 1m x 1.5m x 0.8m with mass of approx. 0.75 tonnes. However, scientists have warned that it may be possible under certain conditions that the back flushing of an intake filter could result in a population density of certain organisms which is high enough to constitute the critical mass required to cause a “bloom”. This would have a negative ecological impact by actually causing an event which ballast treatment is designed to prevent.

Despite the degree of integrity that filtration can introduce to a system, the initial costs as well as maintenance, space and weight constraints could be seen by some Operators as a significant degree of burden.

A different physical separation device, that has great potential for ballast water treatment, is the cyclonic separator. A cyclonic separator has no moving parts and consists of a hollow, central core with a helical geometry that tapers at one end (fig. 12).

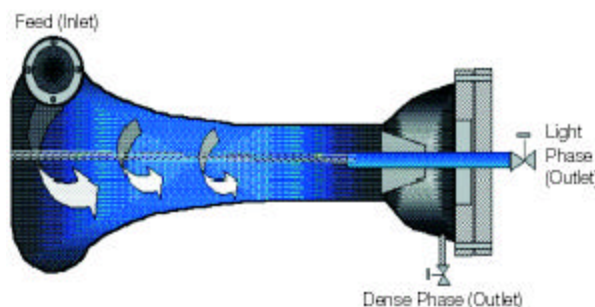


Figure 12 – An illustration of a cyclonic separator with its principle features

With respect to ballast operations, the flow of water enters via the widest section of the core and is subsequently subjected to increasing centrifugal force as it is accelerated down a tapering helical path. The lighter phase, in this case the water, migrates to the central core and the dense phase, in this case organic matter/sediment is expelled to the outer regions of the section. Each phase has an outlet with the dense phase being discharged overboard.

From the perspective of use on board ship, the absence of moving parts is a significant advantage with respect to maintenance and possible modes of failure. It has been reported that the present technology can cope with flow rates between 200m³/hour and 3000m³/hour depending on the equipment installed, which is far in excess of those associated with filtration.

A shipboard application, known to aim for future approval, is the treatment system installed on the MV Regal Princess of Princess Cruises in March 2000. This comprises a two-stage system, combining a hydrocyclone and UV chamber (see fig. 13).

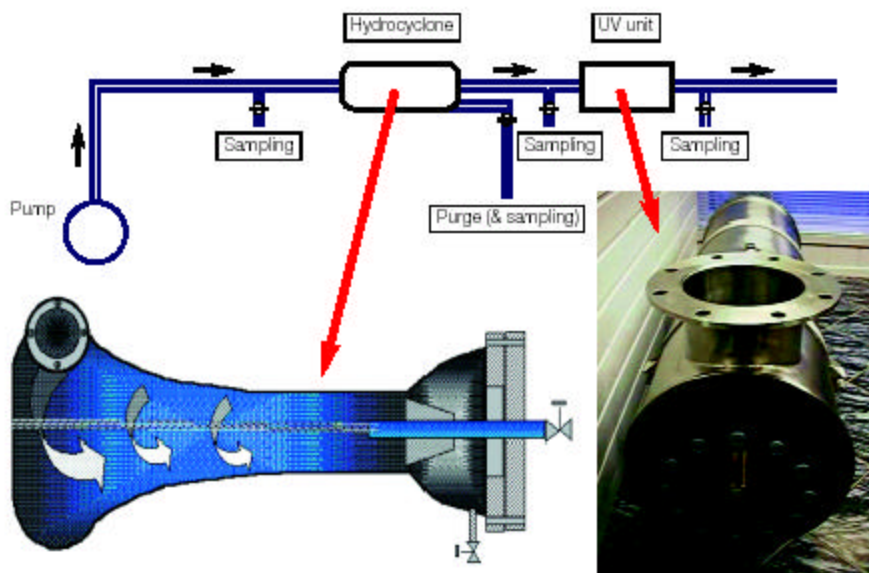


Figure 13 – The treatment system installed on the MV Regal Princess, incorporating hydrocyclone and UV chamber

Could these systems be applied to the major deadweight and freight carriers which carry considerable amounts of ballast water (see Table 1) On the evidence of existing technology, this could be rather difficult. It has been reported, however, that an American manufacturer has developed an ultra-cyclonic separator capable of delivering flow rates of over 10000m³/hour. It is considered that research, including extensive testing, would be necessary for the development of reliable and effective systems with practical flow rates. Some typical capacities of the exclusive ballast pumps of various ship types are reported in Table 5. It is noted that all the reported examples have two exclusive ballast pumps.

Table 5 Typical capacity of the exclusive ballast pump	
Ship type	Capacity (m ³ /hr)
Handysize Bulk Carrier	800
Panamax Bulk Carrier	1000
Capesize Bulk Carrier	2800
Aframax Oil Tanker	1500
Suezmax Oil Tanker	1750
VLCC Oil Tanker	3000
LNG Carrier	2400

8 Conclusion

There will be very few deadweight and freight carriers which would pass with flying colours an assessment against classification, statutory and operational aspects, as those used in the study for the sequential method, using maximum lifetime loads and motions of the ship. The study identified the risks in respect of the sequential method and described options for mitigating these risks. If ballast exchange operations on existing ships, especially those utilizing the sequential method, are carried out without understanding or controlling the risks, then the ship's safety could be endangered.

The Administrations' inability to multilaterally agree and define clearly the acceptable methods, procedure and criteria for ballast water management indicates that the problem is not an easy one to solve. However, this lack of decision-making in the short-term could have long-term consequences for all parties concerned.

The industry should start looking for feasible solutions, which will be acceptable to all parties concerned, in particular Administrations and Operators. Solutions should not be imposed, but be part of a selection process that at the end of the day will satisfy the needs of the Administrations and still will be practical for the Operators.

The ideal ballast water management method would be one that is effective, safe and easy to use and relatively inexpensive to install and maintain. It can be observed that there is no single or simple solution apparent yet to prevent the transfer of harmful aquatic organisms. Understanding of risks and associated impact on the environment and the ship is considered imperative prior to the development of solutions.

The industry's commitment to standardize clear criteria for the assessment of ballast water management is, therefore, essential. Once this has been achieved, the procedure shown in fig. 14 could be followed for the preparation of a ballast exchange plan, identifying which method is used for various ballast tanks and ballast conditions. At the planning phase the user defines the criteria for compliance. Then the user follows several paths until a ballast exchange plan acceptable to all parties concerned is prepared.

It is noted that ships in-service often suffer damages and/or corrosion which could weaken the structural capability against loads generated during ballast exchange at sea operations. Therefore, when strength calculations are performed, consideration should be given to the present condition of the structure. Using the results and the general findings of the LR Study as reference, the user could select suitable ballast exchange methods, thus reducing the overall effort required to prepare an acceptable ballast exchange plan.

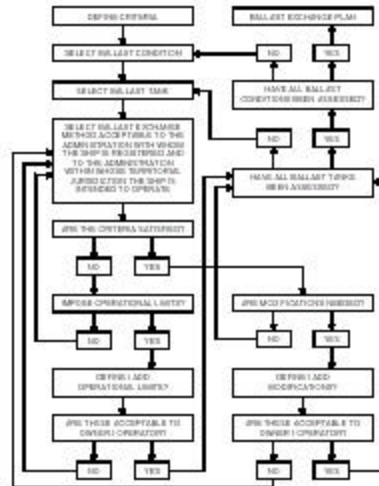


FIGURE 14. Ballast Exchange Procedure

Regulations must make both socio-economic and techno-economic sense. In the case of ballast water management, the former has been dictated by the needs of societies that have been struck by the introduction of harmful aquatic organisms in their waters, subsequently affecting local environments. If the industry finds acceptable solutions that make techno-economic sense, then the regulations will be seen as mature and sensible. The aim of Lloyd's Register of Shipping is to assist the industry to find feasible solutions for all parties concerned.

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